Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

1952

An analysis of tandem helicopter parameters.

Meshier, Charles W.

Princeton University

http://hdl.handle.net/10945/24605

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

DUDLEY KNOX LIBRARY

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

AN ANALYSIS OF TANDEM HELICOPTER PARAMETERS

CHARLES W. MESHIER

1952

Library
U. S. Naval Postgraduate School
Monterey, California

M-56

AN ANALYSIS OF TANDEM HELICOPTER PARAMETERS

Charles W. Meshier
Lieutenant, U. S. Navy
B.S. June 1943 U.S. N.A.
B.S. Aero. Eng. 1951 U. S. Navy P.G.S.

Submitted in partial fulfillment of the
requirements for the Degree of
Master of Science in Engineering
from
Princeton University

Alexander A. Nikolsky
Professor, Department of Aeronautical
Engineering, Princeton University

Thesis
M55

ACKNOWLEDGEMENT

The author wishes to express his thanks to Professor Alexander A. Nikolsky for his assistance and encouragement in suggesting the method of this analysis.

18195

TABLE OF CONTENTS

Page

Summary 1

Introduction 3

Symbols and Conventions 5

Analysis 7

Results and Discussion 10

Conclusions 13

References and Bibliography 14

Formulae and Sample Calculations 15

Tables I. The Static Equation Solution 19

II. Coefficients and Induced Power 20

III. Summation of Power Required 21

Figures

1. Fuselage Attitude Calibration 22
2. Variation of Fuselage Moment 23
3. Variation of Fuselage Drag and Lift 24
4. Variation of Downwash Velocity 25
5. Ratio of Rotor Downwash and Induced Power 26
6. Variation of Parasite Power with Forward Speed 27
7. Ratio of Rotor Parasite Powers 28
8. Power Required 29
9. Transmission Efficiency 30

Page

10. Variation of Collective Pitch with Speed 31

11. Variation of R/C with Airspeed 32

12. Nomenclature Diagram 33

Appendix A - Physical Properties of the HUP - 1 Helicopter 34

SUMMARY

The purpose of this investigation is to extend the method of forward flight analysis of the conventional helicopter to the tandem configuration, and from calculated performance data on a typical tandem type, to evaluate the tandem design and its susceptibility to such analysis.

The problem is considered for only stabilized forward level flight conditions, for which adequate flight test information was available, and the usual assumptions used in forward flight analysis are made. The induced velocity is considered constant over the rotor disc, and the no-feathering axis is assumed coincident with the rotor shaft; that is, the longitudinal cyclic control angle is considered negligible.

Results of the theoretical performance calculations indicate that the tandem configuration is readily adaptable to analysis at hover and at moderate forward velocities. However, in the high speed range from about 60 knots to V_{max}, tilting of the thrust vectors due to flapping, rotor interference effects, stalling of the retreating blade, and compressibility phenomena encountered by the advancing blade contribute increasing power incremements that are difficult to recognize or separate, but are manifest in an unconservative rotor horsepower required estimate.

The tandem configuration appears very promising performance-wise, but a need for more intensified wind tunnel and flight test programs to study the effects of rotor displacement and overlap is indicated. The position of the differential longitudinal trim was also determined to be an important function of the overall tandem performance.

INTRODUCTION

Historically, the practical helicopter is little more than a decade old, and only in recent years have its potentialities received widespread development and recognition. Of the many helicopter configurations currently under development, the two most important are certainly the single rotor and tandem arrangements. Of these, the former is the simpler from both the performance or the stability and control viewpoint, and has received the most attention in the literature. However, the tandem configurations have amply demonstrated their practicability, and as in the case of the single rotor helicopter, the acuteness of performance and structural problems has taken most of the manufacturer's effort. To improve the flying qualities of the helicopter is the problem now.

Significant advances in this respect will be made only when performance parameters are completely defined, and a study can be made of the helicopter's stability and control characteristics. Such a program would facilitate the coordinated development and design of both the helicopter and a matching autopilot.

At present the NACA flight research section at Langley Field is carrying on flight tests of a tandem helicopter, mainly to clarify what aspects of the helicopter's flying qualities are significant to the pilot, and to discover means of improving these flying qualities. The Full-Scale Tunnel Group at Langley Field has a program of testing

model tandem rotors to evaluate the interference effects as the spacing is varied. Their results will probably be invaluable in writing the empirical forms probably required for these effects.

Another flight test program is the proposal for basic research on Tandem Helicopter Stability and Control by the Forrestal Research Center at Princeton University. This plan of theoretical study, flight testing, and data analysis will necessarily include a thorough investigation of performance analysis.

The purpose of this investigation is to extend the method of forward flight analysis of the single rotor helicopter to one of tandem design to determine the range and reliability of performance prediction. Limited flight test data was available from reference 1 on the HUP - 1 model, and a rotor horsepower required curve is calculated from the attitude of the aircraft at nine different speeds and two trim settings.

SYMBOLS AND CONVENTIONS

W	Gross weight of helicopter, pounds
b	Number of blades per rotor
R	Blade radius, feet
r	Radial distance to blade element, feet
c	Blade section chord, feet
c_e	Equivalent blade chord, feet $c_e = \dfrac{\int_0^R c r^2 dr}{\int_0^R r^2 dr}$
σ	Rotor solidity ratio, bc/ R
θ	Blade section pitch angle from zero lift chord line at 0.75 R
v	Axial component of induced velocity at a blade element (0.75 R), feet per second
Ω	Rotor angular velocity, radians per second.
V_m	Calibrated airspeed, feet per second
$\bar{\alpha}_r$	Mean angle of attack of rotor disc,
i	Angle of inclination of the axis of reference to the vertical, degrees
α	Angle of attack, in level flight, degrees
μ	Tip speed ratio, , non-dimensional
λ	Mean inflow factor, , non-dimensional
α_f	Angle of inclination of the fuselage water line to the flight path, degrees
α'_f	Angle of attack of the fuselage measured from the water-line of the fuselage to the resultant velocity vector, degrees
V'	Resultant air velocity at the rotor, feet per second,

T	Rotor thrust, pounds
C_T	Rotor thrust coefficient,
ρ	Air density, slugs per cubic feet
a	Slope of left curve for blade (per radian)
C_{do}	Section profile drag coefficient
δ	Mean profile drag coefficient
B	Tip loss factor,
R_e	Effective blade radius, BR, feet
S_e	Effective rotor disc area, $(RB)^2$, square feet
Cm_f	Fuselage moment coefficient
C_{Df}	Fuselage drag coefficient
C_{Lf}	Fuselage lift coefficient
w	Mean fuselage width
h	Rotor height above reference axis, feet
ℓ	Distance between rotor shaft and center of gravity, fuselage length when not subfixed
H	Horizontal component of force acting on a rotor
M	Total moment
D	Total drag
L	Total lift
P	Total power, horsepower
par	Subfixed to P to indicate Parasite Power
ind	Subfixed to P to indicate induced power
pro	Subfixed to P to indicate profile power
F	Subfixed to rotor parameters to connotate forward rotor
A	Subfixed to rotor parameters to connotate aft rotor

ANALYSIS

An analysis of helicopter performance in forward stabilized flight can be made from a resolution of all the aerodynamic, gravitational and propulsive forces and moments created on the aircraft because of the reaction between it and the air through which it moves. As shown on Fig. 12, the forces acting on a rotor in the longitudinal plane are usually resolved into T (thrust) and H (perpendicular to thrust) components.

The equations for static equilibrium for a tandem configuration then become:

$$T_F + T_A + D_f \sin \alpha_f' = (W - L_f) \cos i$$

$$H_F + H_A + D_F \cos \alpha_f' = W \sin i$$

$$T_F l_F - T_A l_A + H_F h_F + H_A h_A = {}^{*}M_f$$

*where M_f is the total moment of fuselage with tail measured about the aircraft center of gravity.

M_f, L_f, and D_f are assumed known from wind tunnel tests on a fuselage model, and the attitude variation of the aircraft with airspeed is known from flight test data; thus, one is left with three equations and four unknowns. However, from the identical geometry of the HUP - 1 rotors, it is logical to assume that ratio of the T and H forces of one rotor is equal to the ratio of the T and H forces of the other. This relationship,

$$T_F/H_F = T_A/H_A \,,$$

supplies the necessary fourth equation to solve the system.

The further assumption that the no-feathering axis and the rotor shaft are coincident in the longitudinal plane is the practice of the manufacturer and this investigation supports that theory.

For detailed derivations of other equations or expressions used in this analysis, one can refer to reference 2, Helicopter Analysis, by Alexander A. Nikolsky.

In the power required analysis, the energy spent by the helicopter in forward flight is expressed as the sum of the induced, parasite, and profile powers required. In equation form:

$$P = -Tv - TV\sin i + HV\cos i - \frac{1}{8}\rho bc R(\Omega R)^{3}(1+4.65\mu^{2}).$$

where the first term represents the induced power. The second and third terms evaluate the energy spent in moving the aircraft with the horizontal velocity, V, and the last term is the energy spent on the profile drag of the blades, due to rotational motion.

In estimating the parasite power as   , the angular displacement of the thrust vector due to flapping is disregarded, and at the higher speeds this assumption may not be valid. For precise computations the effects of rotor interference would have to be known.

The static equations of equilibrium for the helicopter in stabilized forward level flight are derived and solved for the forces acting on the aircraft, assuming only that the thrust and horizontal forces of one rotor have the same ratio as those of the other. The validity of this assumption is justified by the identical geometry of the rotors.

The remainder of the analysis is a straightforward computation of the downwash velocities and the power required at each rotor, the power required being the sum of the induced, parasite and profile powers. The procedure followed and the formulae used were taken from reference 2, with which a working knowledge is assumed for this investigation.

Comparisons between theoretical and flight test performances are made in general statements only, throughout the report, for security measures.

RESULTS AND DISCUSSION

The data for this investigation is taken from Part II, Appendix "B" of reference 1, the manufacturer's aerodynamic demonstration report on the HUP - 1. The helicopter was flown in stabilized flight conditions at normal rated engine RPM (2500) and indicated airspeeds of approximately 60, 70, 80, 90 (knots) and V_{max}, at both plus and minus $3/4^{\circ}$ trim settings. The actual B.H.P. was computed for each speed and plotted versus the true airspeed. The fuselage attitude was also recorded and is shown in Fig. 1 plotted against calibrated airspeed for two different trim settings, and extrapolated to 0 airspeed.

Then, on assuming an average downwash velocity, the fuselage angle of attack could be determined and the moment lift and drag calculated with coefficients taken from reference 2. The David Taylor Model Wind Tunnel Tests were made at a Reynold's Number and dynamic pressure of the same magnitude as the Flight Tests, and were invaluable in this analysis. The fuselage moment, lift, and drag are shown plotted against airspeed in Figs. 2 and 3.

The Sample Calculation Section of this report illustrates the procedure of the remainder of the calculations and the performance parameters determined are shown plotted against airspeed in Figs. 4 to 11.

Figs. 4 and 5 show the variation and ratios of induced velocity and induced power required by the two rotors plotted against airspeed.

When the ratios are near unity from hover to about 100 f.p.s., predicted performance agrees closely with the flight test results of reference 1, indicating little or no rotor interference effects.

Figs. 6 and 7 present the parasite power required picture, and as would be expected, the tilting forward of the thrust vectors at higher speeds demands an increasing expenditure of energy. The increase in power required by the rear rotor is due to the increase of the fuselage moment. However, the increase of parasite power with airspeed can be considerably reduced at higher speeds by using nose up trim. At V_{max} the difference between 3/4° nose down and 3/4° nose up represents a 10% power saving.

Fig. 8 shows the rotor horsepower required. The forward speed for optimum rate of climb is readily obtained, where the slope is zero, as 93 f.p.s. (55 knots). Fig. 11 is an extension of this data, showing the rate of climb variation with forward velocity. Up to and slightly beyond the speed for best rate of climb the rotor horsepower required predictions check almost exactly flight test results. The best rate of climb was calculated at 1205 f.p.m. at 55 knots as against comparable flight test figures of 1227 f.p.m. at 52 knots, which were obtained at a 5450 lb. gross weight, a 2.5 inch fwd c.g. and a 1/4° nose down trim.

However, beyond about 100 f.p.s. the rotor power required curve diverges rapidly from the measured engine B.H.P. required, as is shown in Fig. 9, which presents their ratio. In this region the effect of rotor tip paths tilt due to flapping and the effects of rotor interference become an appreciable power loss that can only be

calculated by difference. The problem is further complicated by the possibility of the retreating blade stalling and the advancing blade encountering compressibility phenomena at speeds near V_{max}. Fig. 10 is a plot of the collective pitch setting at each rotor, and it is seen that near V_{max} the retreating blade of the rear rotor is approaching the stalling point.

The results of this investigation emphasize the necessity for a thorough flight test program which could separate and measure these unknown power increments. It is believed that the Tandem Helicopter Stability and Control Study Proposals of the Forrestal Research Center at Princeton University will definitely clarify the performance of the tandem configuration, as the first step to analyzing the important stability and control problems.

CONCLUSIONS

This analysis has shown that the performance of the tandem helicopter configuration can be accurately analyzed from hover throughout the moderate speed range, and that the differential longitudinal trim is an important function of performance.

It is recommended that further study of this problem be made in the high speed region to determine the parameters of rotor interference and the angular displacement of the tip path plane due to flapping.

REFERENCES AND BIBLIOGRAPHY

1. "Aerodynamics Demonstration Report, Section 'B'", September 1951, Piasecki Helicopter Corporation, Morton, Pennsylvania.
2. Nikolsky, Alexander A., "Helicopter Analysis", 1951, John Wiley and Sons, Inc., New York.
3. Beebe, John and Bradshaw, H.R. "Wind-Tunnel Tests of A 1/7-Scale Model of the XHJP-1 Helicopter Fuselage", July, 1949, David Taylor Model Basin Report No. C-245 Aero. 773.
4. Gessow and Myers, G.C. jr., "Aerodynamics of the Helicopter", 1952, The Macmillan Company, New York.
5. Stepniewski, W.F., "Introduction to Helicopter Aerodynamics", 1950, 3rd ed., Rotorcraft Publishing Committee, Morton, Pennsylvania.

FORMULAE AND SAMPLE CALCULATIONS

All flights were made at a density altitude of 1500 feet at the same 2 in. fwd c.g. position. Runs 1 to 5, inc., were made at a 3/4° nose up trim setting and runs 6 to 15, inc., were made at a 3/4° nose down trim setting.

A sample performance calculation is presented for run 11. Reference can be made to Figs. 2 and 3 and Tables I, II, and III for specific values.

The equations of static equilibrium for the aircraft in stabilized forward flight are solved:

$$T_F + T_A = [(W-L)\cos i - D\sin\alpha_f']$$

$$H_F + H_A = [W\sin i - D\cos\alpha_f']$$

$$T_F/H_F = T_A/H_A$$

$$l_F T_F - T_A l_A + H_F h_F + H_A h_A = M$$

from which:

T_F = 2525 lbs

T_A = 2703 lbs

H_F = 298 lbs

H_A = 317 lbs

Since $\alpha = -i$ and $\mu = V\cos\alpha/\Omega R$, λ, the mean inflow factor is then determined for each rotor by trial and error from:

$$\tan \alpha = \frac{\lambda}{\mu} + \frac{1}{2}\,\frac{C_T}{B^2 \mu (\mu^2+\lambda^2)^{1/2}}$$

where:

$$C_T = \frac{T}{\pi R^2 \rho (\Omega R)^2} \; ; \quad B = 1 - \frac{\sqrt{2 C_T}}{b}$$

$$\lambda_F = -0.0340 \qquad \lambda_A = -0.035$$

The induced velocity at each rotor is computed:

$$v = \frac{\frac{1}{2} C_T \Omega R}{B^2 (\lambda^2 + \mu^2)^{1/2}}$$

$$v_F = 7.26 \text{ ft/sec.} \qquad v_A = 7.76 \text{ ft./sec.}$$

The induced power required is then simply Tv.

$$P_{IND_F} = 18{,}350 \ \frac{\text{ft-lb.}}{\text{sec.}} \; ; \quad P_{IND_A} = 21{,}000 \ \frac{\text{ft-lb}}{\text{sec.}}$$

The parasite power is the energy spent in moving the aircraft forward, or $P_{par} = TV \sin i - HV \cos i$.

$P_{par_F} = 27400 - 24900 = 2500$

$P_{par_A} = 29400 - 26500 = \underline{2900}$

P_{par} . . . . $= 5400 \ \frac{\text{ft-lbs}}{\text{sec.}}$

To determine the profile power, the mean angle of attack of the rotor is determined; a drag coefficient is calculated and multiplied

by a factor of 1.3 to account for contributions of [illegible] control rods; and the profile power is computed from the accepted equation,

$$P_{pro} = -\frac{1}{8}\rho b c R(\Omega R)^3 \delta\,(1+4.65\mu^2)$$

$$\overline{\alpha}_r = \frac{2C_T}{a\sigma} \quad \frac{B^3}{3}+\frac{\mu^2 B}{2}$$

$$C_{d_0} = 0.0113 - 0.027\,\overline{\alpha}_r + 0.52\,\overline{\alpha}_r^2$$

$$\delta = 1.3\,C_{d_0}$$

Hence,

$$P_{pro_F} = 48{,}300 \quad \frac{ft.-lbs}{sec.}$$

$$P_{pro_A} = 49{,}400 \quad \frac{ft.-lbs}{sec.}$$

$$RHP_{(req.)} = 259 \quad \text{Horsepower}$$

$$\text{Vertical } R/C_{max} = \frac{\Delta HP\,(33000)}{G.W.}$$

$$R/C_{max} = 1135 \text{ fpm}$$

R/C_{max} = 1135 f.p.m. at 50 knots forward speed which checks closely with the Flight Test result of 1224 f.p.m. at a trim setting of 1/4° nose down at sea level.

The collective pitch angle is also calculated and plotted from:

$$\theta = \frac{\left[\frac{2C_T}{a\sigma} - \frac{1}{2}\lambda\left(B^2 + \frac{1}{2}\mu^2\right)\right]}{\left[\frac{B^3}{3} + \frac{1}{2}\mu^2 B\right]}$$

TABLE I

The Static Equation Solution

Run	V_m ft/sec	α_f degrees	v (assumed) ft/sec	α_f' degrees	C_{mf}	C_{Lf}	C_{Lf}	q lbs/ft^2	M ft-lbs
1	102.5	0	6	-3.3	-0.285	0.335	0.375	11.8	-2455
2	119.3	-1	5	-3.4	-0.285	0.385	0.57	15.15	-3360
3	136	-4	5	-6.1	-0.285	0.37	0.43	20.9	-4350
4	151.1	-3	4	-9.5	-0.287	0.355	0.25	26.0	-5450
5	161.2	-9	4	-10.4	-0.29	0.355	0.2	29.7	-6290
6	0	7	25	-90	0	-	-	0.71	0
7	16.9	5.5	21	-45.6	-	-	-	0.324	-100
8	33.8	4	17	-22.7	-0.275	0.445	-.02	1.3	-261
9	50.6	2.6	13	-12.3	-0.29	0.355	0.10	2.91	-616
10	67.5	1.1	10	-7.3	-0.285	0.36	0.375	5.16	-1073
11	84.5	-.4	8	-5.8	-0.282	0.37	0.44	8.1	-1563
12	102.5	-2	6	-5.35	-0.280	0.375	0.48	11.9	-2435
13	113.5	-4	5	-6.42	-0.285	0.37	0.415	15.3	-[illegible]10
14	135.4	-9	5	-11.1	-0.290	0.355	0.170	20.3	-4400
15	153	-11	4	-12.5	-0.290	0.357	0.100	26.5	-5510

Run	D lbs	L lbs	i degrees	sin i	cos i	sin α_f'	cos α_f'	k_1 lbs	k_2 lbs
1	113.0	176.2	7	0.122	0.991	-0.0581	0.998	5157	538
2	116.5	239.2	8	0.139	0.99	-0.0593	0.998	5090	568
3	201.0	233.5	11	0.191	0.981	-0.1062	0.995	5065	828
4	290.0	169.0	15	0.2585	0.965	-0.165	0.985	5065	1154
5	274.0	154.5	16	0.2755	0.96	-0.18	0.984	5064	1212
6	10.0	-4.0	0	0	1	-1.0	0	5392	0
7	10.4	-4.0	1.5	0.0262	1	0.715	0.7	5390	134
8	15.0	-0.676	3	0.0525	1	-0.386	0.924	5384	263
9	26.3	7.55	4.4	0.0767	1	-0.211	0.976	5376	386
10	48.3	30.2	5.9	0.1025	0.99	0.127	0.99	5301	504
11	78.0	92.5	7.4	0.1287	0.989	-0.101	0.995	5228	615
12	116.0	149.0	9	0.1565	0.986	-0.0931	0.995	5166	726
13	153.0	171.8	11	0.191	0.981	-0.112	0.995	5127	876
14	192.0	91.9	16	0.2755	0.96	-0.1923	0.98	5112	1293
15	246.0	68.9	18	0.309	0.95	-0.213	0.975	5099	1422

TABLE II

Coefficients and Induced Power

Run	T_F lbs	T_A lbs	H_F lbs	H_A lbs	$\tan\alpha$	μ	λ_F	λ_A	$1+4.65\mu^2$
1	2480	2677	258	280	-0.1223	0.191	-0.03425	-0.0354	1.1695
2	2380	2710	274	312	-0.1402	0.222	-0.04025	-0.04145	1.239
3	2260	2805	370	458	-0.1941	0.2505	-0.0560	-0.0530	1.292
4	2105	2960	430	674	-0.268	0.2745	-0.0799	-0.0824	1.3505
5	2045	3019	991	720	-0.2865	0.2913	-0.0891	-0.09195	1.395
6	2875	2517	0	0	0	0	-0.0498	-0.0466	1.0
7	2820	2570	70	64	-0.0262	0.0318	-0.04465	-0.0422	1.0047
8	2770	2614	137	130	-0.0524	0.0635	-0.0349	-0.0336	1.0187
9	2710	2666	195	191	-0.0766	0.0952	-0.0307	-0.03035	1.042
10	2628	2673	248	255	-0.1028	0.1257	-0.0305	-0.0308	1.0734
11	2525	2703	298	317	-0.130	0.1570	-0.0340	-0.035	1.1145
12	2430	2736	342	385	-0.1563	0.1901	-0.04015	-0.0415	1.1682
13	2320	2807	397	479	-0.1941	0.2135	-0.0513	-0.0532	1.222
14	2195	2917	555	738	-0.2865	0.2442	-0.0775	-0.08	1.278
15	2020	3079	563	859	-0.3245	0.273	-0.09455	-0.09765	1.346

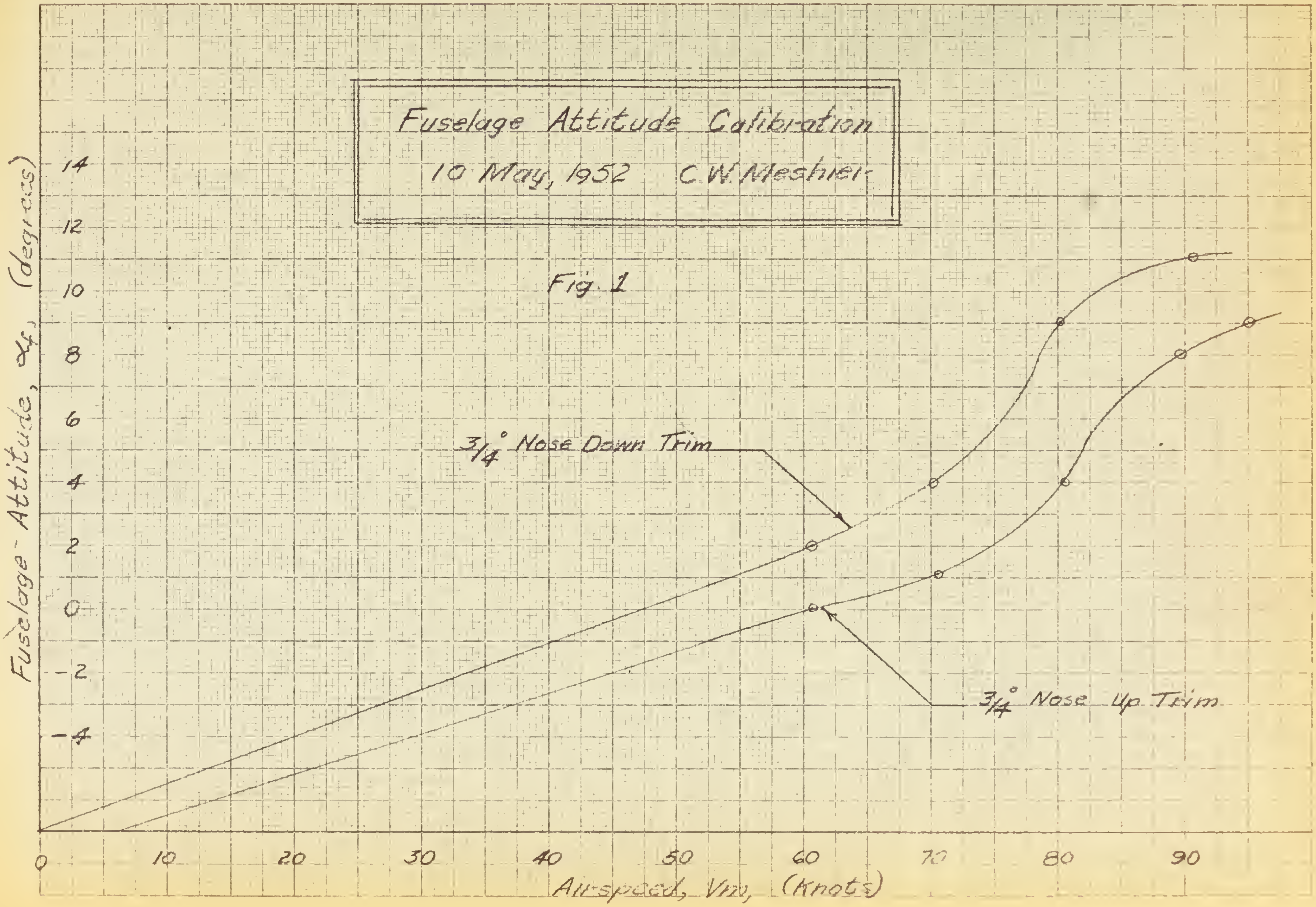
Run	v_F ft/sec	v_A ft/sec	P_{IND_F} ft-lbs/sec	P_{IND_A} ft-lbs/sec	C_{T_F}	C_{T_A}	B_F	B_A
1	5.8	6.48	14400	17225	0.00401	0.004325	0.97	0.969
2	4.9	5.49	11670	14380	0.00386	0.00439	0.971	0.969
3	4.01	4.97	9050	13950	0.00367	0.00455	0.9717	0.9682
4	3.35	4.745	7050	14010	0.0034	0.00478	0.9727	0.9672
5	3.04	4.527	6215	13670	0.00329	0.00485	0.9728	0.967
6	26.5	24.8	76100	62450	0.00465	0.00407	0.968	0.97
7	23.4	22.0	67200	56500	0.004565	0.00416	0.9683	0.97
8	16.80	16.10	46500	42100	0.004485	0.00423	0.9683	0.97
9	12.45	12.25	33700	32650	0.00439	0.004315	0.9684	0.9684
10	9.46	9.52	24810	25420	0.004255	0.00433	0.969	0.969
11	7.26	7.76	18350	21000	0.004115	0.004385	0.97	0.969
12	5.57	6.275	13550	17190	0.00394	0.00443	0.9703	0.9687
13	4.715	5.74	10935	16100	0.00376	0.00458	0.9712	0.9683
14	3.92	5.27	8600	15370	0.00355	0.004725	0.9717	0.9677
15	3.197	4.88	6455	15005	0.00327	0.00498	0.373	0.9668

TABLE III

Summation of Power Required

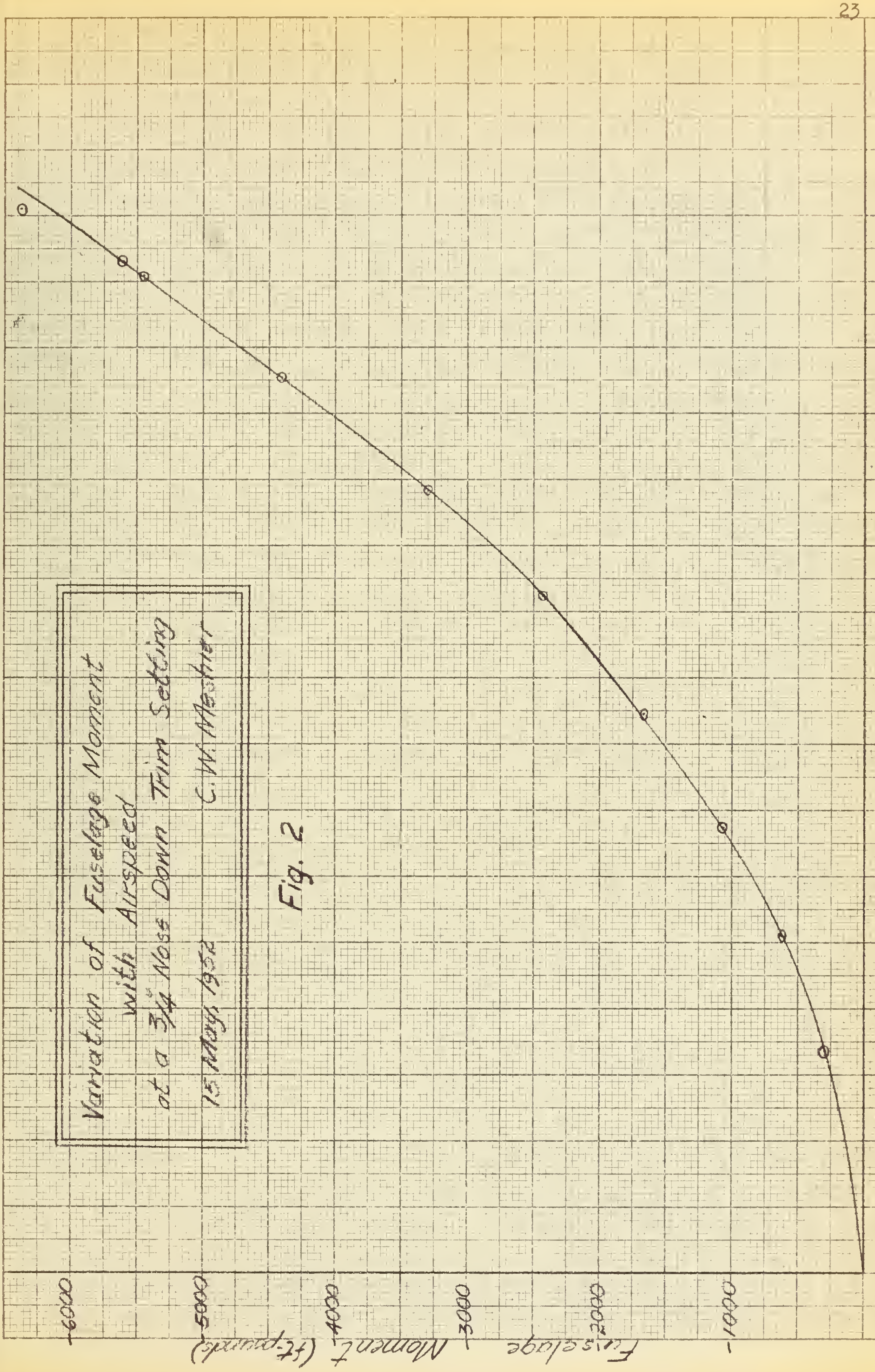
	$\bar{\alpha}_{r_F}$	$\bar{\alpha}_{r_A}$	C_{d_F}	C_{d_A}	$T_F V \sin i$	$T_A V \sin i$	$H_F V \cos i$	$H_A V \cos i$	P_{par}
Run	radians	radians			foot pounds per second				
1	0.0687	0.0714	0.01184	0.01198	31000	33400	26200	28450	9750
2	0.0668	0.074	0.01171	0.01211	39700	45000	32400	36800	15500
3	0.06025	0.0754	0.01155	0.01218	58700	72900	49300	61150	21150
4	0.0546	0.0779	0.0114	0.01237	82250	115500	70000	98250	29500
5	0.0522	0.078	0.01135	0.01237	90750	134000	76000	111500	37250
6	0.0348	0.0738	0.01275	0.01214	0	0	0	0	0
7	0.0325	0.0752	0.01261	0.01221	1250	1137	1182	1077	128
8	0.0312	0.0761	0.01254	0.01226	4900	4620	4645	4405	470
9	0.0781	0.0772	0.01237	0.0123	10530	10350	9875	9690	1315
10	0.0755	0.077	0.01222	0.0123	18190	18500	16600	17050	3040
11	0.0719	0.077	0.01204	0.0123	27400	29400	24900	26500	5400
12	0.0676	0.0761	0.01182	0.01227	38950	43800	34550	38900	9300
13	0.0634	0.07725	0.01167	0.01239	52500	63500	46150	55600	14250
14	0.0586	0.07865	0.01151	0.0124	81800	108750	72150	96000	22400
15	0.0526	0.0815	0.0113	0.01254	95500	145400	81900	124900	34100

Run	P_{pro} ft-lb./sec	RHP (req)	BHP (req)	η %	R/C ft/min
1	94300	246.5	288.5	85.5	1107
2	101000	260.0	304	85.5	1053
3	103750	267.0	348	76.7	710
4	109150	290.0	433	67.0	276
5	113050	310	494	62.8	24.5
6	84750	405	450	90.0	276
7	84950	380	-	90.0	429
8	87250	284.2	-	89.9	1001
9	87350	282.0	-	89.55	1002
10	89700	260.0	-	89.45	1142
11	97700	259.0	-	88.75	1125
12	96300	248.0	283	87.0	1165
13	99900	257.0	312	82.4	943
14	102400	270.2	380	71.0	521
15	109500	300	498	60.25	6.3


Fuselage Attitude Calibration

10 May, 1952 C.W. Meshier

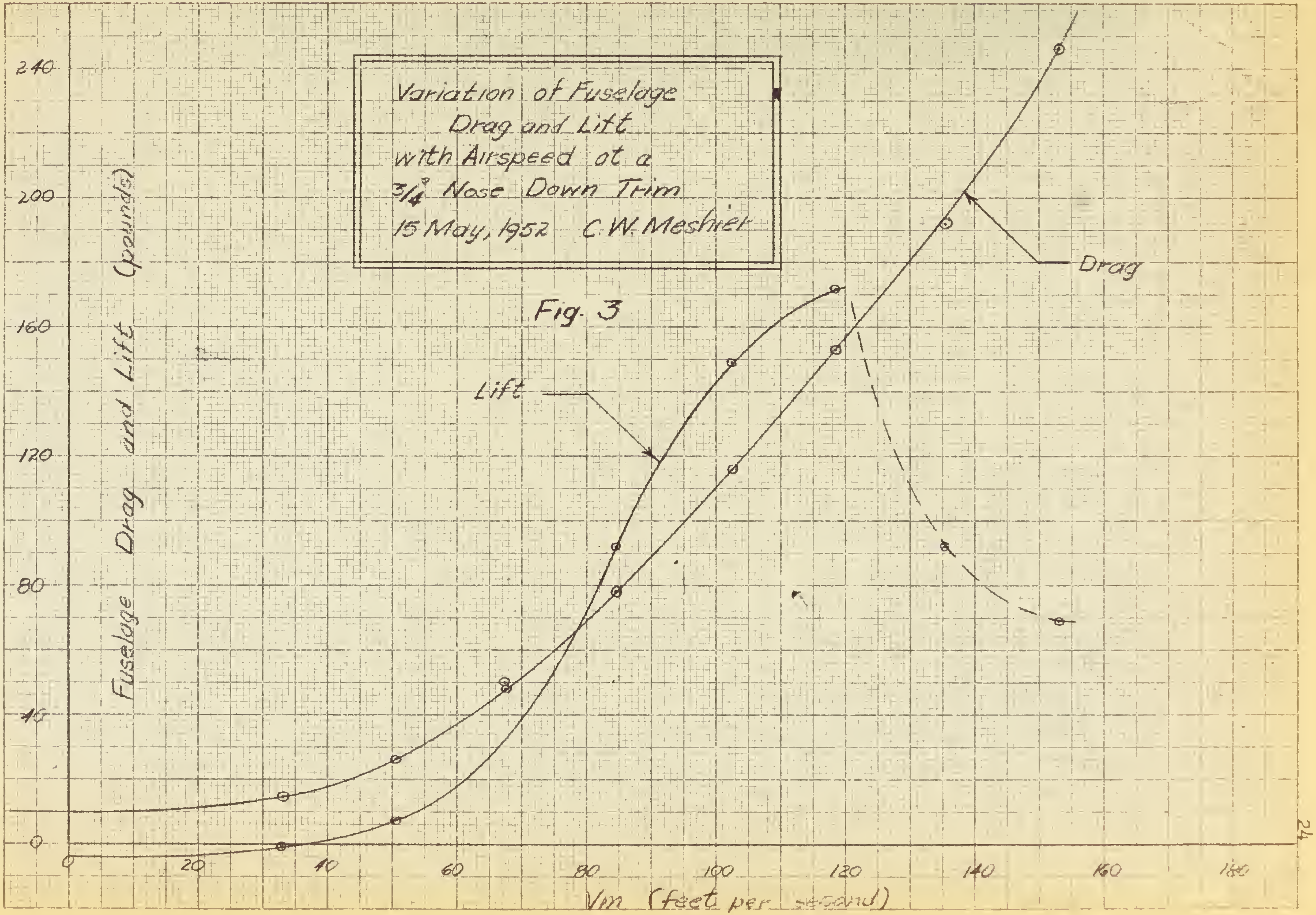
Fig. 1



Variation of Fuselage Moment with Airspeed at a 3/4" Nose Down Trim Setting

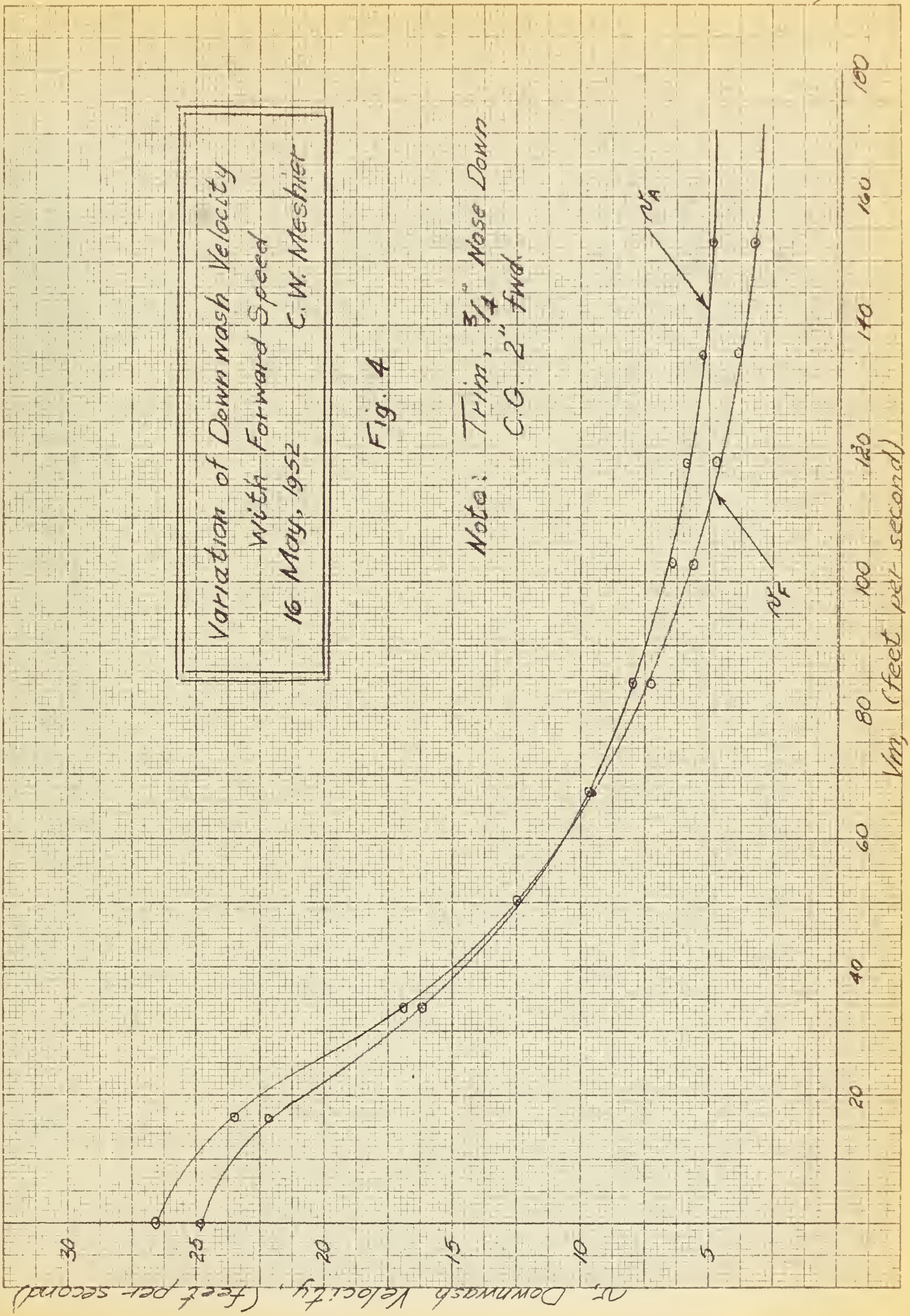
15 May 1952 C. W. Mesther

Fig. 2



Variation of Fuselage
Drag and Lift
with Airspeed at a
3/4° Nose Down Trim
15 May, 1952 C. W. Meshier

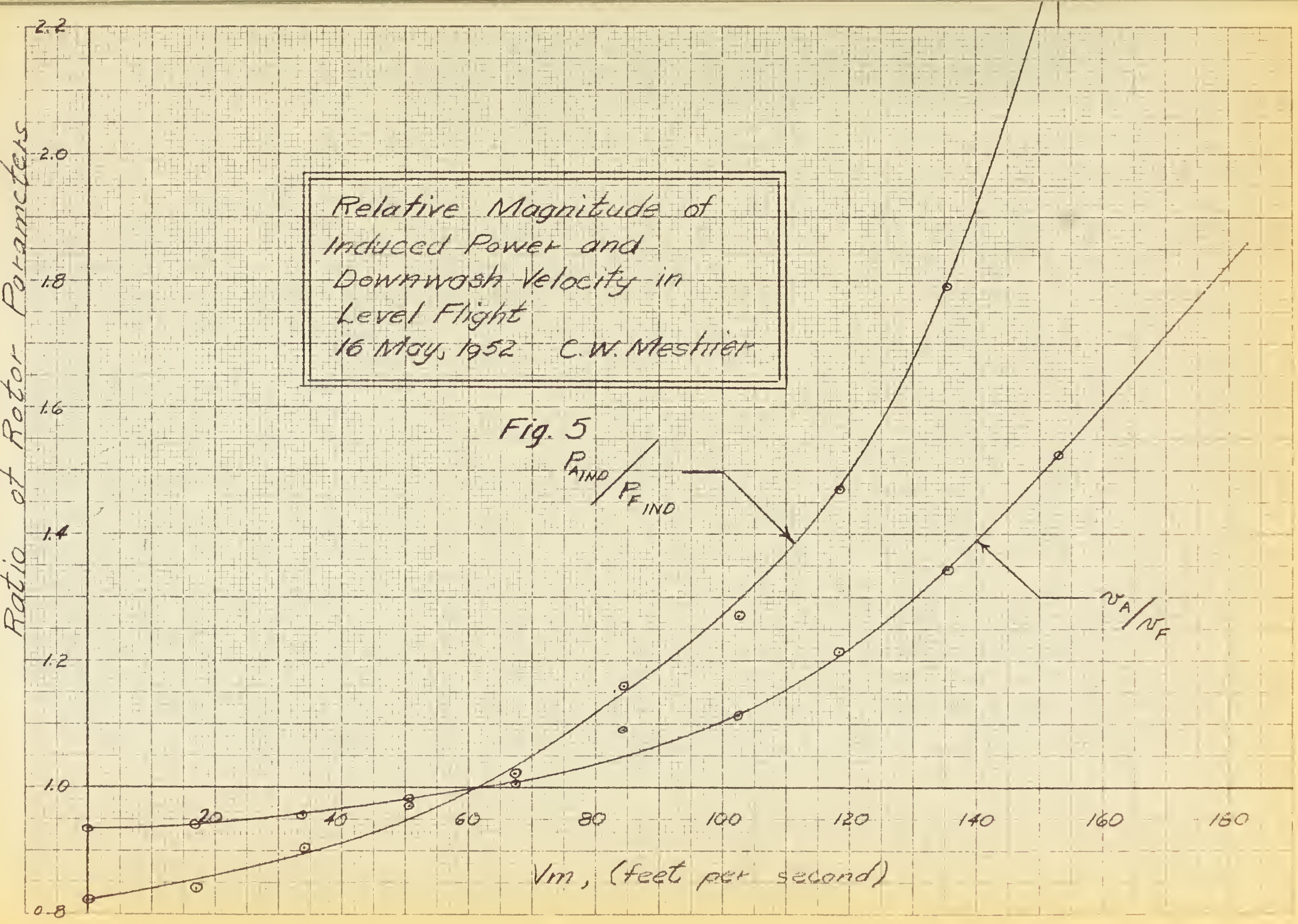
Fig. 3



Variation of Downwash Velocity
with Forward Speed
16 May, 1952 C. W. Meshier

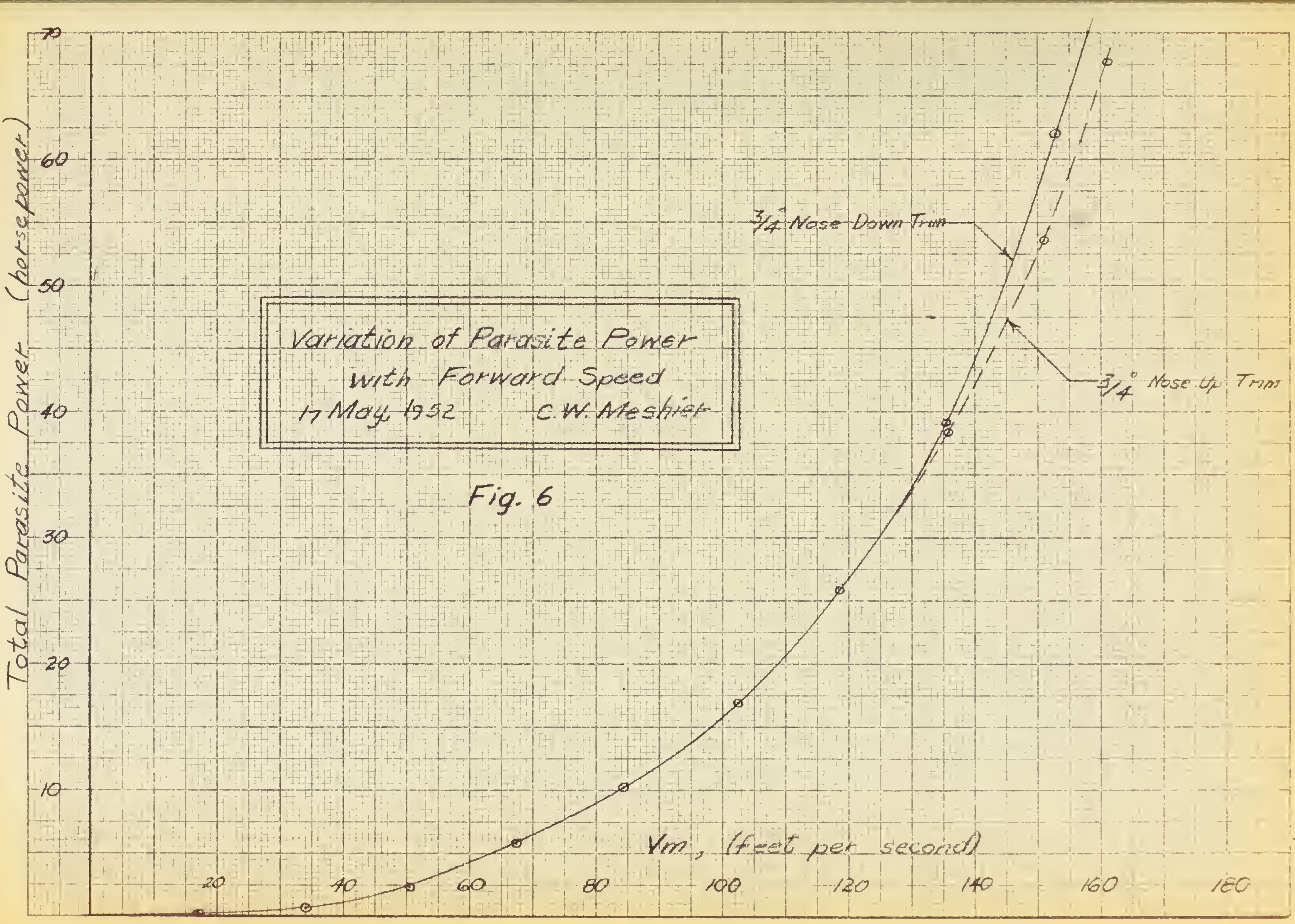
Fig. 4

Note: Trim, 3/4° Nose Down
C.G. 2" Fwd.



Relative Magnitude of
Induced Power and
Downwash Velocity in
Level Flight
16 May, 1952 C. W. Meshier

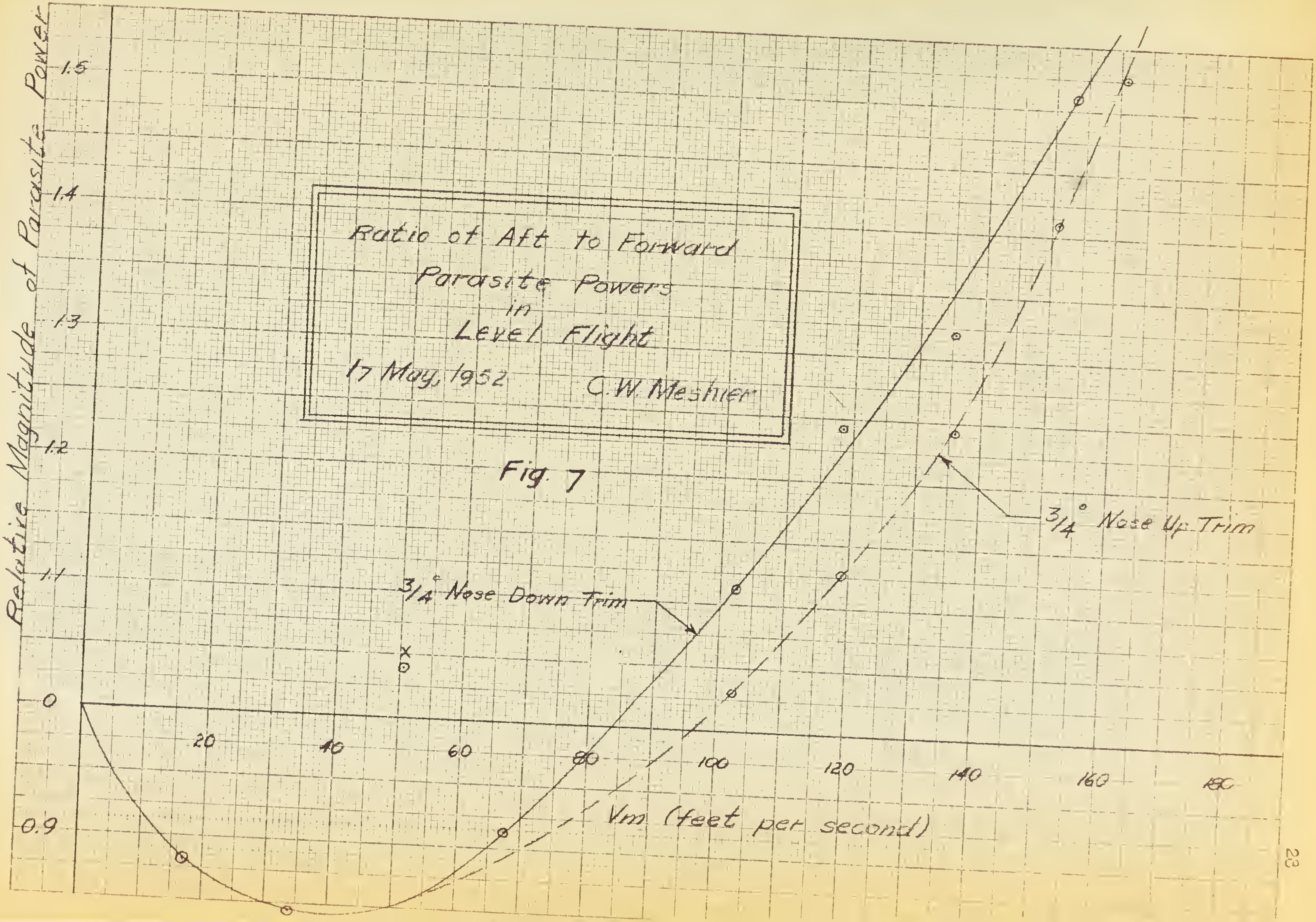
Fig. 5



Variation of Parasite Power with Forward Speed

17 May 1952 C. W. Meshier

Fig. 6



Ratio of Aft to Forward
Parasite Powers
in
Level Flight

17 May, 1952 C.W. Meshier

Fig. 7

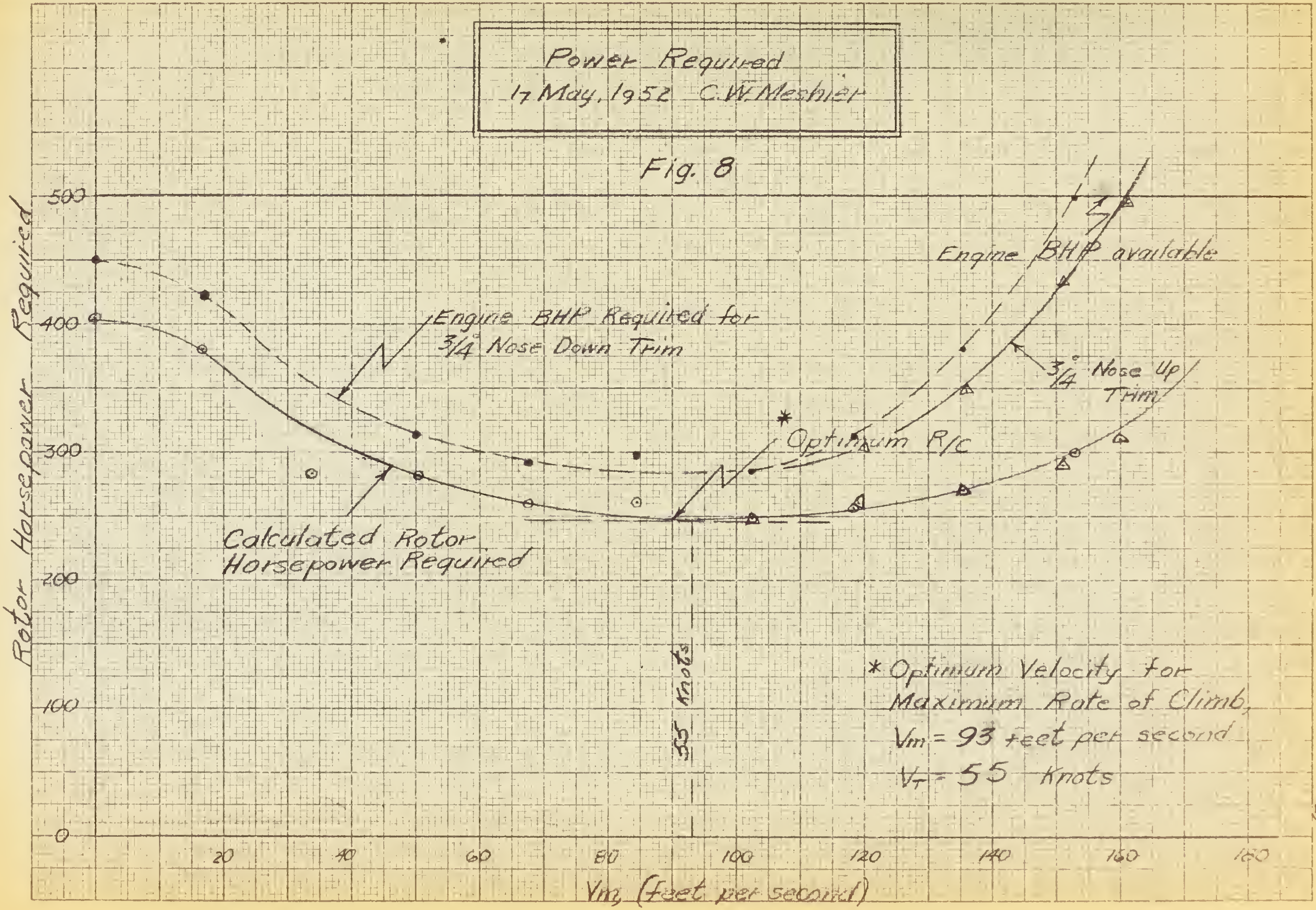
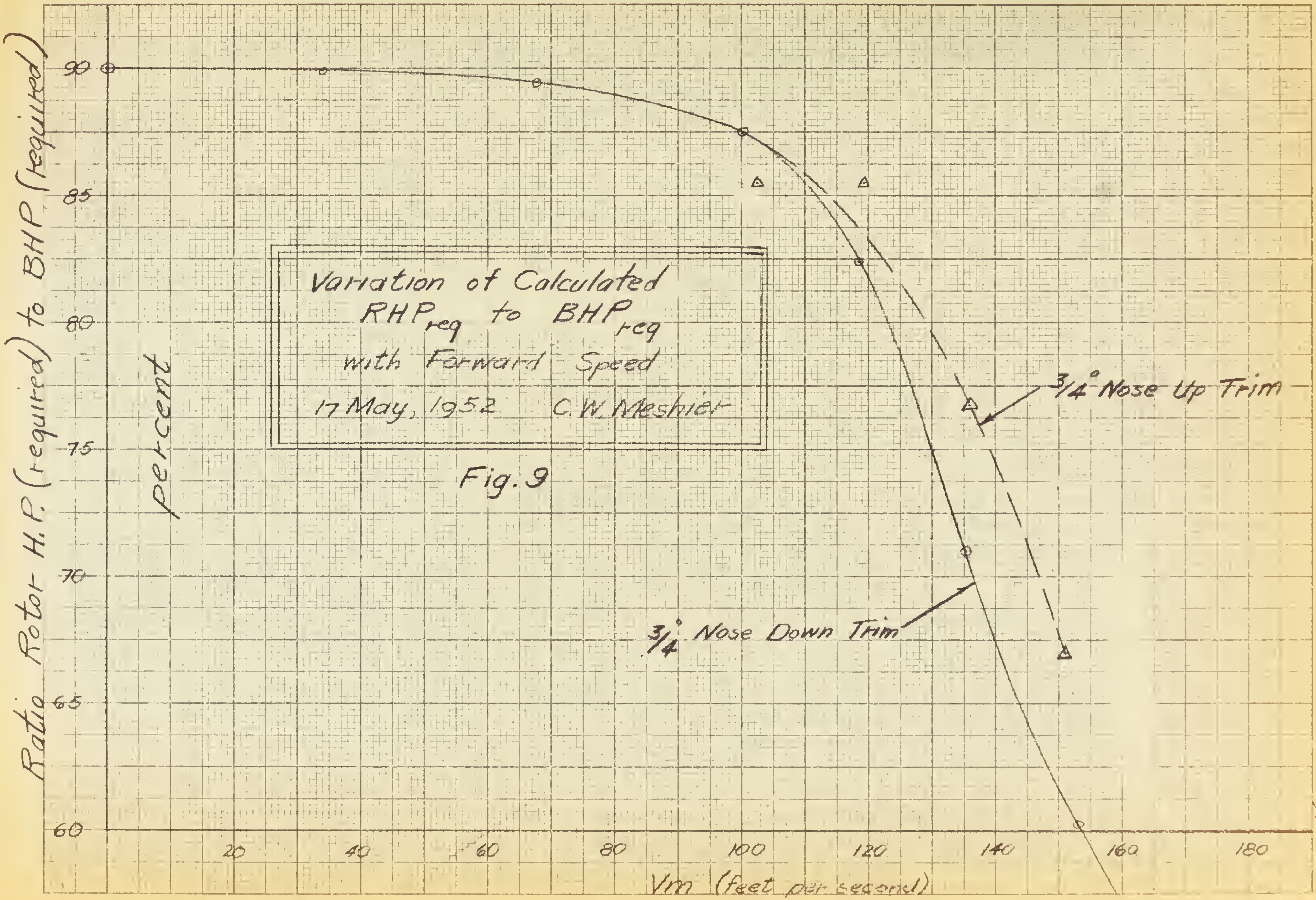


Fig. 8

Power Required
17 May, 1952 C.W. Meshier
Engine BHP Required for 3/4° Nose Down Trim
Engine BHP available
3/4° Nose Up Trim
Optimum R/C
Calculated Rotor Horsepower Required
55 Knots
* Optimum Velocity for Maximum Rate of Climb,
Vm = 93 feet per second
VT = 55 Knots
Rotor Horsepower Required
0
100
200
300
400
500
20
40
60
80
100
120
140
160
180
Vm, (feet per second)



Variation of Calculated
RHP_{req} to BHP_{req}
with Forward Speed
17 May, 1952 C. W. Meshier

Fig. 9

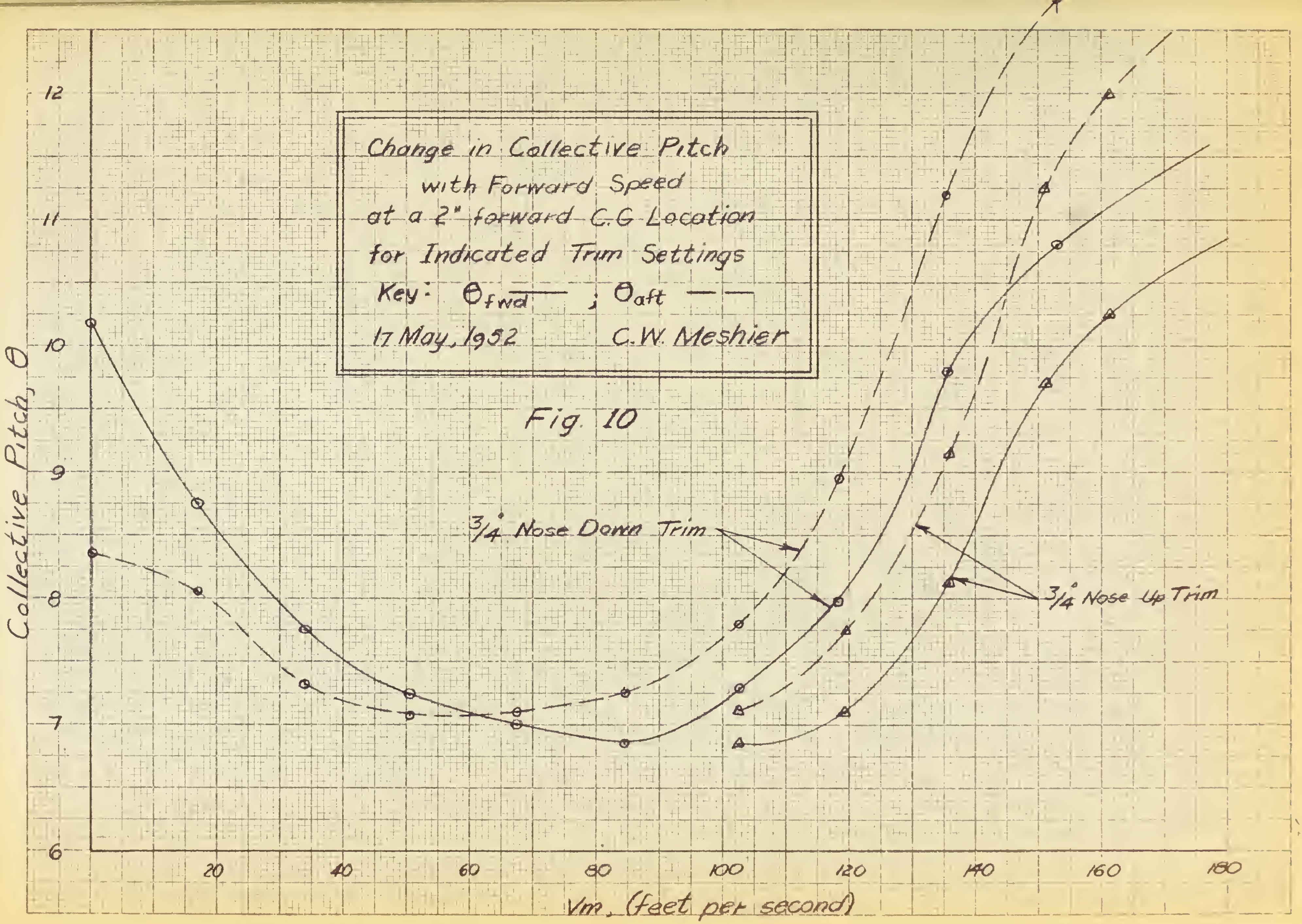
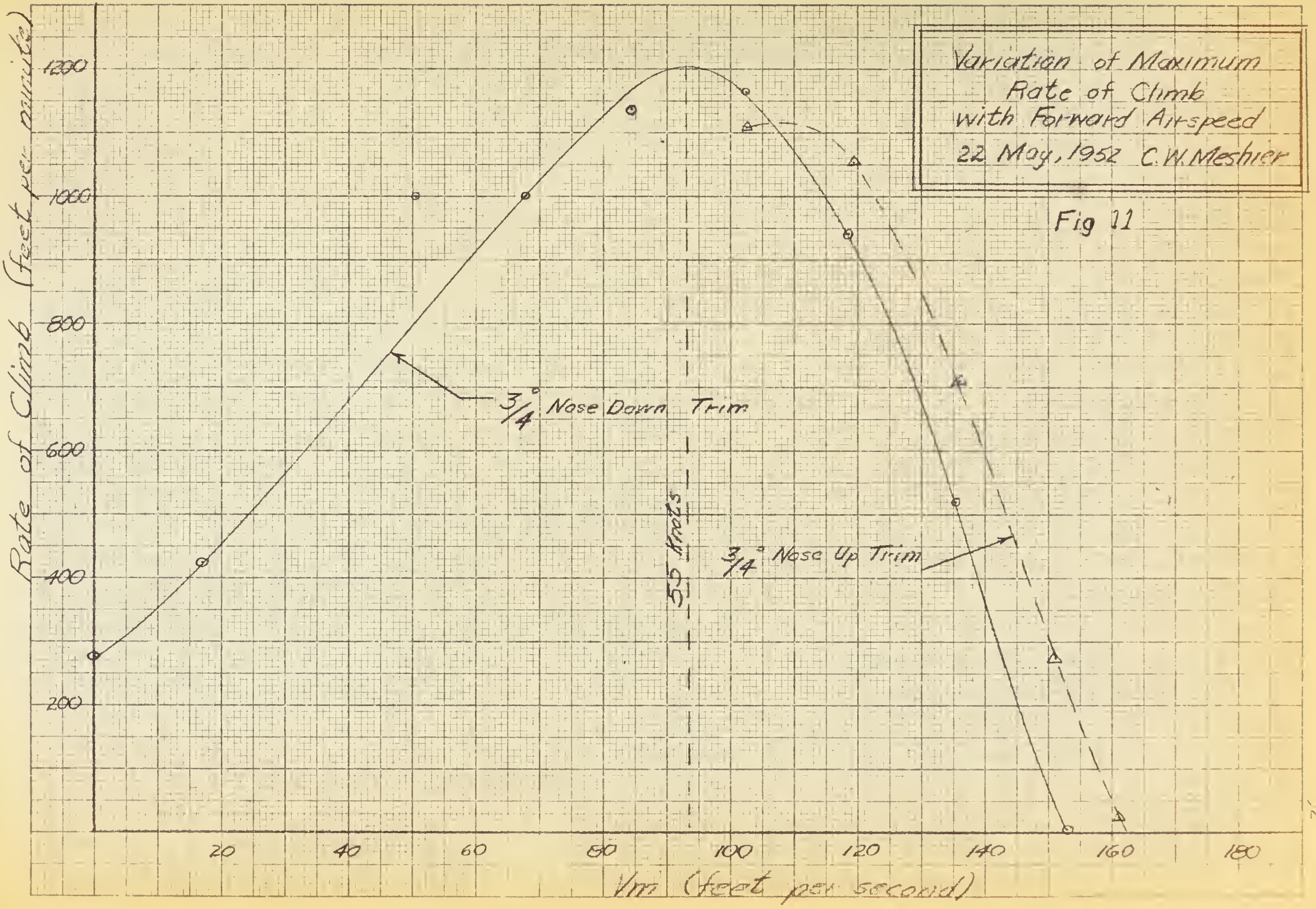
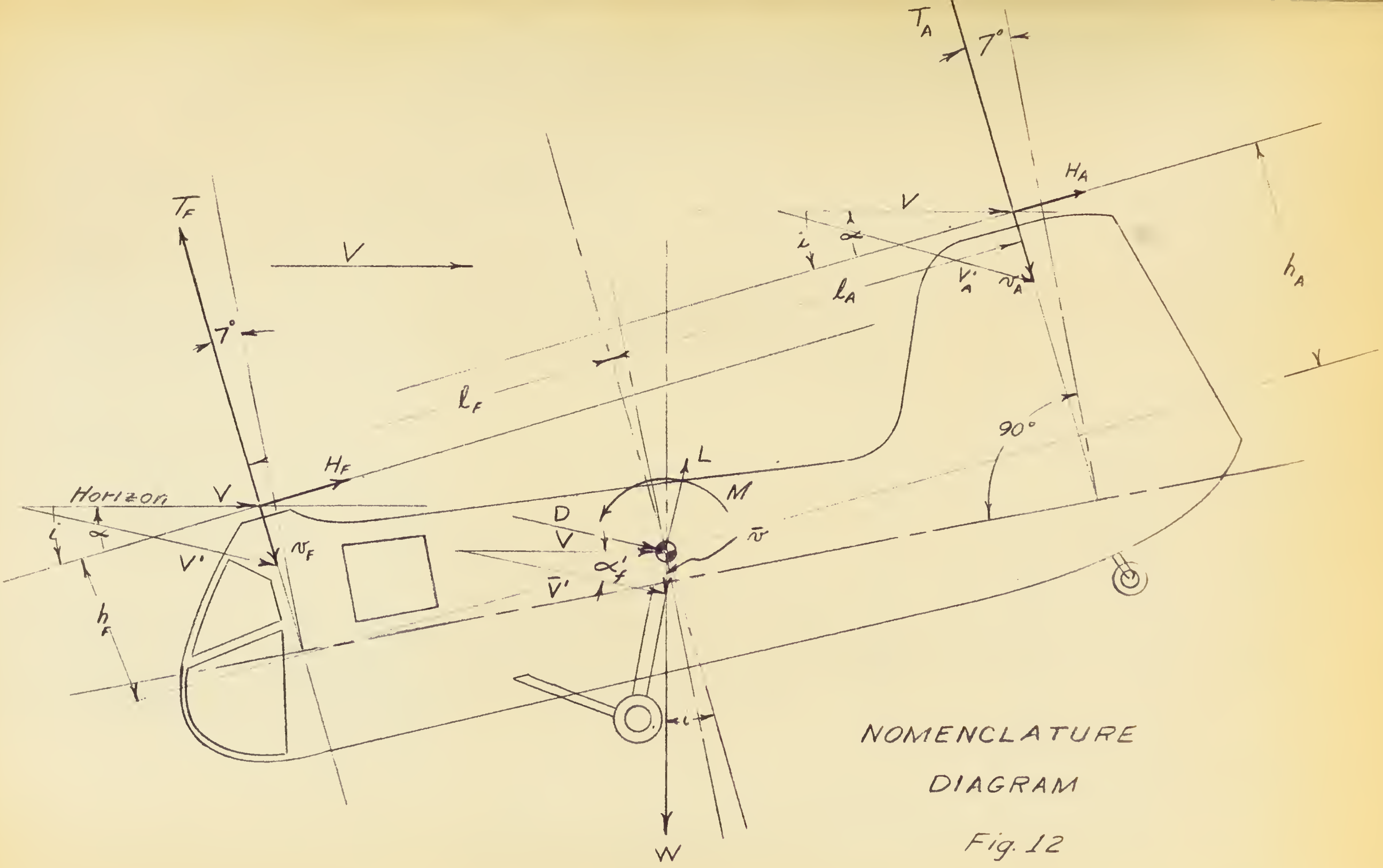

Change in Collective Pitch
with Forward Speed
at a 2" forward C.G Location
for Indicated Trim Settings
Key: θ_{fwd} ——— ; θ_{aft} — —
17 May, 1952
C.W. Meshier
3/4° Nose Down Trim
3/4° Nose Up Trim
Collective Pitch, θ
6
7
8
9
10
11
12
Vm, (feet per second)
20
40
60
80
100
120
140
160
180

Fig. 10



Variation of Maximum
Rate of Climb
with Forward Airspeed
22 May, 1952 C.W. Meshier

Fig 11



NOMENCLATURE

DIAGRAM

Fig. 12

22 May, 1952 C.W. Meshier

APPENDIX A

The helicopter used in this analysis is the HUP - 1, which has the following physical properties:

Gross Weight	5373 lbs.
Center of Gravity (Normal c.g., 6.2 in. fwd. of ℄ between rotors)	2 in. fwd.
l, (distance between rotors)	21 ft. 11 in.
h_F	5.276 ft.
h_A	6.86 ft.
R	17.5 ft.
Ω	290 r.p.m.
b (per rotor)	3
a (per radian)	5.7
$\frac{b\,C_e}{\pi R}$	0.0636

Power Plant

Engine	Continental Model R-975-34
Normal Power	500 H.P. @ 2500 RPM (from sea level to 6700 ft.)
Take-off Power	525 H.P. @ 2300 R.P.M. (at sea level)

Blades

Airfoil Section Basic NACA 00 Series

Chord (28.5 to 34% Span) NACA 0014.9 ..... 12.6 in.

Chord (34 to 62.5% Span) NACA 0013.9 ..... 12.3 in.

Chord (62.5% Span to Tip) NACA 0012 ..... 12.0 in.

Profile Drag Expression; $C_{d_o} = 0.0113 - 0.027\bar{\alpha}_r - .52\bar{\alpha}_r^2$

(The profile drag equation was taken from reference 4 and multiplied by a factor of 1.3 to account for metal blades. Drag coefficients obtained checked very closely with those used by the manufacturer.)

Note 1. The rotor shafts of this helicopter are inclined at an angle of 83° to the fuselage reference axis.

JUL 2 BINDERY

Thesis
M55
18195
Meshier
An analysis of tandem helicopter parameters.
Band
★ BINDERY

Thesis
M55
18195
Meshier
An analysis of tandem helicopter parameters.

Library
U. S. Naval Postgraduate School
Monterey, California

ARTISAN
GOLD LETTERING
AND
SMITH BINDERY
OAKLAND, CALIF.

thesM55
An analysis of tandem helicopter paramet
3 2768 001 88279 8
DUDLEY KNOX LIBRARY